

# Monitoring of Computer Installations for Power Line Disturbances

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## Significance:

Part 3: Recorded surge occurrences and surveys

Part 5: Monitoring instruments

This conference paper (which was not later published in the *IEEE Transactions*, now difficult to retrieve and therefore reproduced here in extenso with discussion submitted to IEEE but also unpublished) presents the result of monitoring what became known as "Power Quality" at selected IBM computer installations. The authors classified disturbances in three categories:

1. "Voltage Spikes" – now labeled surges
2. "Oscillatory decaying disturbances" – now labeled switching surges
3. "Undervoltages and occasional overvoltages" now labeled sags or dips and swells

In the context of an anthology on surge protection and the recording of surges, the paper and discussion are included for three reasons:

### **Instrumentation limitation**

The authors report only low "spike" levels in the period of monitoring (starting in 1969 and concluded in 1972), compared with other contemporary surveys (all before the introduction and proliferation of low-voltage metal-oxide varistors). Because the initial measurements were based on an expectation of moderate surges, the instrumentation range did not include higher values and therefore would miss them or incorrectly record them if and when they would occur, leading to a self-fulfilling prophesy. The discussion – submitted to IEEE immediately after the presentation of the paper but not published because of the lingering Conference Paper status – offered a possible explanation for that apparent discrepancy as being a limitation of the amplitude and sweep speed ranges selected for the storage oscilloscopes.

### **Importance of threshold selection**

Some statistical reports on powerline disturbances have attempted to rank disturbances by order of frequency of occurrence, sometimes presenting pie charts on respective percentages of surges, sags, swells, etc. within the total of recorded disturbances. With hindsight, this approach neglected the fact that the number of occurrences included in these statistics is strongly influenced by the threshold at which the counting begins. Capsule quotations appeared in published articles creating the impression that one type of disturbance is more frequent than another – the winner in the number game being the disturbance for which the threshold was set the lowest. Depending on the field of interest of the researchers conducting the monitoring, the thresholds were generally set logically and understandably at a level where the disturbances begin being a problem for the specific category of interest, hence a disparity of threshold selection among different surveys.

### **Misquotation of the paper**

The conclusions correctly emphasize the significance of sags, swells, and switching surges, but with little attention given to "spikes" (surges). Nevertheless, this paper has been cited as evidence that large surges do not happen, or hardly ever occur, hence the need to include the discussion in the anthology and maintain proper perspective.

## MONITORING OF COMPUTER INSTALLATIONS FOR POWER LINE DISTURBANCES

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## ABSTRACT

A study was made of three-phase, 208 and 240 volt power sources supplying typical data processing equipment. Monitors capable of detecting a wide range of voltage conditions, including those most likely to affect the operation of the equipment, were installed at representative data processing installations. Duration and amplitude plots of three types of disturbances are presented. Average incident rates are computed, and incident-rate versus number-of-sites plots are included.

## INTRODUCTION

Data processing equipment is being used more and more for real-time data operations such as process controls, reservation systems, and time sharing applications; it is also employed for such critical business uses as inventory control and check processing. Such increased dependence on data processing has led to increased interest in power-line disturbances and their possible effects on data processing equipment.

Papers that discuss the sources and types of disturbances existing on power lines are available (see References 1 to 5). They cover the following general types of short-term voltage variations that power lines experience.

- (1) Voltage spikes due to lightning, power-network switching, and the operation of customer equipment. These spikes are typically of short duration (10 to 100 microseconds); bursts of such pulses may also occur with each burst lasting as long as a millisecond or more. Voltage changes of 150% or more of peak nominal ac voltage may be experienced. Spikes of nanosecond duration may also occur.
- (2) Oscillatory, decaying disturbances due to power-factor-correction-capacitor-switching and other network or load switching. These disturbances have a frequency range of from 400 Hz to 5 kHz or more, with beginning amplitudes of up to 100% or more of nominal power peak voltage. Normally they will decay to zero within one cycle of the ac power voltage.
- (3) Undervoltages (occasionally overvoltages) of greater duration than 1/2 cycle of the power voltage caused by faults and the resulting actions of the fault-clearing devices;

or abnormalities caused by large load changes and the resulting actions of the utility-regulating devices and procedures.

Even though information on causes of power-line disturbances is available, monitoring results at user locations, showing range of voltage deviation and disturbance duration, are not available (to the best of our knowledge) in the literature. However, one report on the results of monitoring for voltage spikes is available.<sup>[6]</sup>

All three types of disturbances can cause the malfunction of data processing equipment. Hence, information concerning the voltage profile, duration profile, and frequency of occurrence are of direct interest in determining power system design criteria.

## MONITORS USED

To cover the wide range of time durations involved in power-line disturbances, it was necessary to devise special monitoring equipment.<sup>[7]</sup> For preliminary monitoring (phase one), two automatic recording cathode-ray oscilloscope and 35mm camera combination monitors were developed (analog monitors). Two oscillograph-type recording monitors, manufactured by the Hathaway Corporation, of Denver, Col., were also used.

For final monitoring (phase two), a smaller monitor requiring less servicing and no analysis of waveforms was developed.

## PHASE ONE MONITORING

The objectives of phase one monitoring were:

- (1) To verify the three types of disturbances described in the introduction.
- (2) To determine appropriate characteristics for an improved monitor.
- (3) To obtain preliminary information on the magnitude, duration, and rates of occurrence of power-line disturbances.

Phase one of the monitoring was begun in July 1969 and was completed after the first week of November 1970. Approximately 38 monitor months of data were recorded during this 16-month period. The four monitors, two analog and two oscillograph (Hathaway), were used to monitor a series of locations expected to produce the three types of power-line disturbances described in the introduction.

## Phase One Data

In compiling the data from phase one monitoring, certain ground rules were used. These rules are given below for each of the three classes of disturbances.

Overvoltage or Undervoltage Longer Than 1/2 Cycle of the Power Frequency

## CONFERENCE PAPER

C 74 199-6. A paper recommended by the IEEE Surge Protective Devices Committee of the IEEE Power Engineering Society for presentation at the IEEE PES Winter Meeting, New York, N.Y., January 27-February 1, 1974. Manuscript submitted August 31, 1973; made available for printing December 7, 1973.

Price: Members \$1.50  
Nonmembers \$2.00  
At Meeting: \$1.00

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- (1) Only the largest undervoltage incident within any 2-minute period was counted.
- (2) Unless a voltage dip exceeded 10%, it was not plotted.
- (3) Two types of points were used in the plot.

“0” points were used when all the line-to-line voltages dipped more than 20%.

“x” points were used when at least one of the line-to-line voltages did not dip more than 20%.

- (4) Both “0” dips and “x” dips were plotted at the value of the greatest line-to-line dip.

Figure 1 shows the plot of all undervoltage disturbances from phase one monitoring. No short-term overvoltages greater than 10% were observed. This figure presents a visual picture of the density function (magnitude and duration) of the disturbances recorded.

#### Oscillatory Decaying Disturbances (Switching)

The following rules were established.

- (1) It was not considered necessary to note the duration of the oscillatory disturbances. (Only one was observed to last longer than 16 milliseconds.)
- (2) Only disturbances greater than 10% amplitude were plotted.
- (3) When disturbances appeared on more than one phase, only the greatest of the three line-to-line disturbances was plotted.

The results are shown in Figure 2. This figure presents a visual picture of the density function in magnitude of the disturbances recorded.

#### Voltage Spike Disturbances

For the voltage spike disturbances, only two sites were monitored at sweep speeds fast enough to determine spike width. No disturbances of less than 10% were plotted. The plots of the spikes monitored are shown in Figure 3.

#### Incident-Per-Month Plots

Another useful presentation of the data is a plot of the number of sites versus their recorded incident rate per month. These plots are shown for undervoltage disturbances in Figure 4 and for oscillatory disturbances in Figure 5. It was assumed that the rate observed would continue throughout the year. This is not true, but the site did experience the rate plotted for the monitored period, and, thus, the rates plotted are actual rates experienced.

These plots showed a higher-than-expected incident rate (Figures 4 and 5). The rates exceeding the 10% level were the following.

- a. Undervoltages: Average of data, 5.66 per month; range, 0–12.3 per month (median, 3.5).

- b. Oscillatory decaying: Average of data, 42.2 per month; range, 1.00–110 per month.
- c. Voltage spikes: Only two sites were monitored; the rates were 2.00 incidents per month and 23.0 incidents per month.

#### Results of Phase One Monitoring

- A. Phase one of the monitoring did verify the occurrence of the three types of disturbances described in the introduction.
- B. Phase one of the monitoring program did produce a substantial amount of data on rate of occurrence, magnitude, and duration of power line disturbances.
- C. Phase one monitoring resulted in the establishment of the following operating and physical requirements for phase two monitors.
  - (1) Operation for extended periods of time without maintenance.
  - (2) No film-developing requirement.
  - (3) No analysis-of-waveform requirements. (Disturbances must be separated into type, magnitude, and duration, as required; hence the name “Digital Monitors”.)
  - (4) A hard copy output from the monitor.
  - (5) The monitor must be small and light in weight.

#### PHASE TWO MONITORING

The objectives of phase two monitoring were:

- (1) To obtain a representative sample of typical data processing installation input power disturbances.
- (2) To obtain information on the magnitude, duration, and rates of occurrence of these disturbances.

Phase two monitoring began in June 1970 and had accumulated approximately 109 monitor months of data from the digital monitors when completed in July 1972.

In order to obtain as representative a sample of monitored locations as possible, the following factors were considered in the selection of monitored sites.

- (1) A climatic and geographic cross section of the U.S.
- (2) A cross section of the major types of utility loads (heavy industry, light industry, office and retail stores, residential, mixed).
- (3) A cross section of the major types of utility transmission and distribution networks (isolated, power pool, overhead distribution, underground distribution, single-feeder, dual-feeder).
- (4) A cross section of data processing system density.

## Phase Two Data

In compiling the data from phase two monitoring, a slightly different format was required because the data had already been grouped into ranges by the monitors. The settings of the various sense levels of the monitors determined the ranges used to present the data.

Wherever possible, the ground rules used were the same as those for phase one monitoring. The particulars for each of the three types of disturbances are listed below.

### Overvoltages or Undervoltages Longer Than 1/2 Cycle of the Power Frequency

All the ground rules were the same as those for phase one, except for the addition of the following rules involving overvoltages.

For overvoltages, the only sense level was +10%. Thus:

“0” points are those where all line-to-line overvoltages were more than 10% in magnitude.

“x” points are those where at least one of the line-to-line overvoltages did not exceed 10% in magnitude.

Figure 6 shows a plot of all overvoltage and undervoltage disturbances from phase two monitoring. This figure presents a visual picture of the density function (magnitude and duration) of the disturbances recorded.

### Oscillatory Decaying Disturbances (Switching)

The ground rules for the oscillatory disturbances were the same, except that disturbances below 15% were ignored, and the ranges for grouping the disturbances were determined by the monitor settings and were different from those for phase one. The summary plot of phase two monitoring is shown in Figure 7. The number of disturbances recorded is shown inside the block, while the number of monitor days needed to accumulate the data is shown outside the block, at the top.

### Voltage Spike Disturbances

The voltage spike disturbances were grouped into ranges by the monitor settings. The summary plot of phase two monitoring is shown in Figure 7. The number of disturbances recorded is shown inside the block, while the number of monitor days needed to accumulate the data is shown outside the block, at the top.

### Incident-Per-Month Plots

The plots for phase two of the monitoring of the number of sites versus their recorded incident rate per month for the three types of disturbances are shown in Figures 8, 9, and 10.

### Results of Phase Two Monitoring

- A. Following the ground rules, a series of sites was selected and monitored.
- B. Incident magnitude plots for the three types of disturbances are shown in Figures 6 and 7.

## C. Incident Rate Plots

These plots have provided very interesting data. Continued high rates of incidence were observed as indicated in phase one of the monitoring (Figures 8, 9, and 10). The rates were:

- a. Undervoltages: Average of data, 14.4 per month; range, 0–117 per month. Median of data, 4.5 per month. Moving the undervoltage threshold to 20% undervoltage changes this average to 2.09 per month and range to 0–8.2 per month. Removing the 10 to 20% undervoltages eliminates the high number of occurrences monitored at locations which operated for extended periods of time near the 10% undervoltage threshold.
- b. Oscillatory Decaying: Average of data, 62.6 per month; range, 0.395–185.0 per month (at 15% threshold).
- c. Voltage Spikes: Average of data, 50.7 per month; range, 1.19–95.1 per month (at 25% threshold).
- d. Monthly Distribution of Power Line Disturbance Incident Rates

Figure 11 illustrates how the incident rates vary throughout the year. The plot represents an average of the monthly incidents from two consecutive years to try to minimize effects of unusual storm activity during one of the periods. Voltage dips between 10% and 20% are not included here because large numbers of them came from very few locations and would have biased this plot for the months that these few locations were monitored. As one might expect, the summer months, with their lightning storms, produced the highest incident rates.

- e. Outages vs Duration (Figure 12)

This plot, “Cumulative Percent of Outages vs Duration in Minutes,” is based on 65 outages monitored during a total of 109 monitor months at 29 locations. It is extremely useful for estimating the effectiveness of a certain number of minutes of power buffering. The average outage rate was 0.6 incidents/month.

## D. Monitor Data by Location

There is a tremendous variation in the disturbances recorded at the different locations. In general, city locations, with their underground distribution systems and networks, have relatively few severe undervoltages or outages but have a substantially higher number of oscillatory disturbances. A few locations showing an extremely high rate of 10% – 20% undervoltages were found to be actually operating at a low steady-state voltage during certain periods of the day. In two cases, the data processing customer took corrective action by having transformer taps changed after being informed of the monitoring results.

## Comparison of Undervoltage Results from Phase One and Phase Two Monitoring

One would expect the incident rates from the phase one monitoring to be substantially higher than phase two because the sites had been selected in anticipation of the presence of certain types of disturbances. Therefore, it was surprising to find the average incident rates higher for the phase two monitoring. All of this increase in undervoltage incident rates can be attributed to those few locations already mentioned that were operating at low voltage and exhibited a very high number of 10% – 20% undervoltages. The sensor circuits used on the analog monitors were designed so they would not be triggered on gradual changes and, therefore, would not have indicated many of these incidents even if they were present at the phase one locations.

Because severe undervoltages are very infrequent, their study requires as large a data base as possible. For this reason, we have combined the undervoltage data from 109 monitor months of the phase two study with 38.4 monitor months of the phase one study and an additional 24.3 monitor months of data gathering with the analog monitors following completion of the phase one study. This 171.7 monitor months of data from 49 locations is presented on Figure 13 as a density plot of "Undervoltage Incidents vs Cycles Duration."

### Distribution of Disturbances by Shift

All monitoring was done on a 24-hour-per-day, 7-day-per-week basis.

A study of a sample of the data to determine the distribution of undervoltage incidents by shift revealed that 42% of the incidents occurred in the first shift (9:00 a.m. to 5:00 p.m.), with 28% in the second shift (5:00 p.m. to 1:00 a.m.) and 30% in the third shift (1:00 a.m. to 9:00 a.m.). About 60% of the disturbances exceeding 43% magnitude occurred during the first-shift hours, with the remainder about equally divided between the second- and third-shift hours.

## STATISTICAL CONSIDERATIONS

The statistical validity of the data is increased when a relatively large number of monitoring locations is chosen. Also, an extended period of monitoring is necessary to determine the rate for less frequent disturbances. However, given the number of monitors available and a limited time period for the monitoring project, the estimated actual population mean incident rates computed by the usual statistical procedures for the 90% confidence level is significant.

For the combined undervoltage data, the computed 90% confidence level of the actual total mean, derived from the observed means of 43 monitored locations, is  $11.4 \pm 5$  incidents per month. A sample size four times as large would be necessary to halve the spread at the 90% confidence level.

For the digital oscillatory disturbances exceeding the 30% threshold, the computed 90% confidence level of the actual total mean, derived from the observed means of 19 monitored locations, is  $34.6 \pm 14.7$  incidents per month. The sample size for the digital voltage spike data is 18 locations. The computed 90% confidence level of the total mean for voltage spikes exceeding the 50% threshold is  $17.1 \pm 2.4$  incidents per month. For both of the above, a sample size four times as large would also halve the spread at the 90% confidence level.

Inherent in the above calculations of the expected total means computed from the sample means are three important assumptions that are necessary in applying the usual statistical procedures.

- (1) The seasonal variation is similar at all locations.
- (2) There is no variation in the data from year to year.
- (3) The sample is statistically random.

We know that the third assumption is not valid because an effort was made to make the sample representative, rather than random. This effort will probably result in the sample being closer to the population than a limited random sample would be. Of course, there is no positive assurance that the sample selected is really representative, in spite of efforts to make it so.

We also know that the second assumption is not precise, and we know of no generally accepted way of estimating the year-to-year variation. Also it seems reasonable to suspect that the first assumption is not precise. The effect of the actual imprecise nature of the assumptions is to introduce a possible bias in the calculated results.

In spite of the possible bias, we are unaware of any collection of data better tailored to the needs of data processing and control equipment manufacturers. We can only hope that, in the future, additional data will be available to help increase the sample size and to help answer the questions about year-to-year and seasonal variations.

## CONCLUSION

UPS equipment is required for reliable continuous operation of electronic equipment through the wide range of disturbances found on power lines.

The monitoring data presented can be used by industry or professional society committees to determine appropriate design criteria to make electronic equipment less sensitive to power-line disturbances. Both types of data plots used in this paper (magnitude vs duration, and incident rate) are useful. The magnitude and duration plots can be used for setting appropriate design limits and determining the number of incidents that lie outside proposed or selected design limits. Plots of incident rate versus sites can show the effect of selected design limits across a profile of customer locations. In other words, the data can be used to provide information about the probable conditions at "worst site" installation, as well as the overall average effects of selected or proposed design criteria.

Until appropriate standards are established, the design susceptibility limits of electronic equipment must remain the individual responsibility of each manufacturer.

## REFERENCES

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(5) W. E. Master and A. Hauspurg, "What the Industrialist Should Know and Do When Arranging to Obtain Utility Power," AIEE General Meeting, Conference Paper Number CP61-829, June 1961.

(6) Francois P. Martzloff and Gerald J. Hahn, "Surge Voltages in Residential and Industrial Power Circuits," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-89, No. 6, July/August 1970.

(7) George W. Allen, "Design of Power-Line Monitoring Equipment," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-90, No. 6, November/December 1971.

ACKNOWLEDGMENT

The authors wish to thank all those involved in this data-collection process, especially Mr. R. E. McKinney and Mr. J. R. Lowney. We also wish to thank Dr. Yen Bin Chen for his help with statistical data.

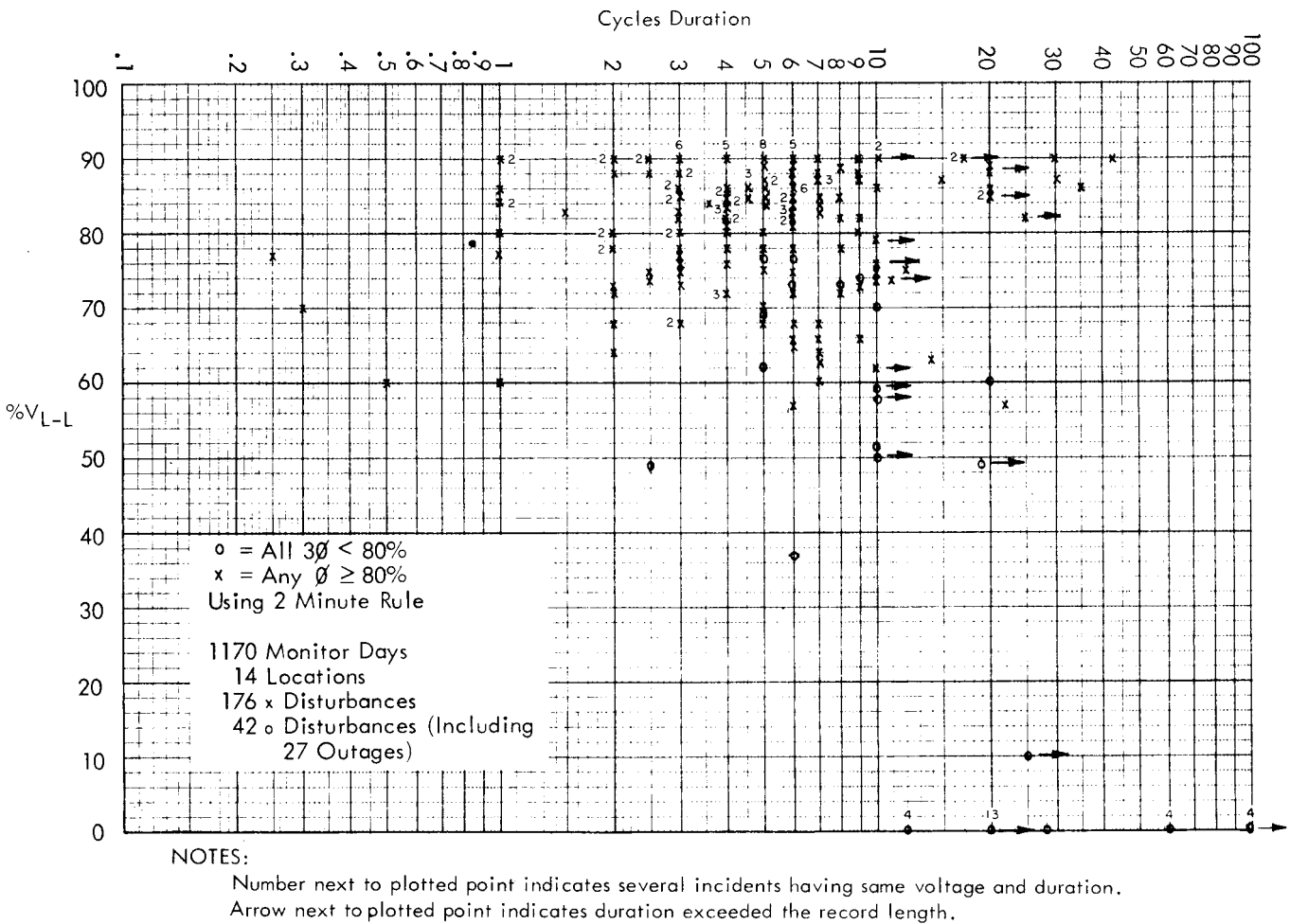


Figure 1. Plot of Undervoltages From Phase One

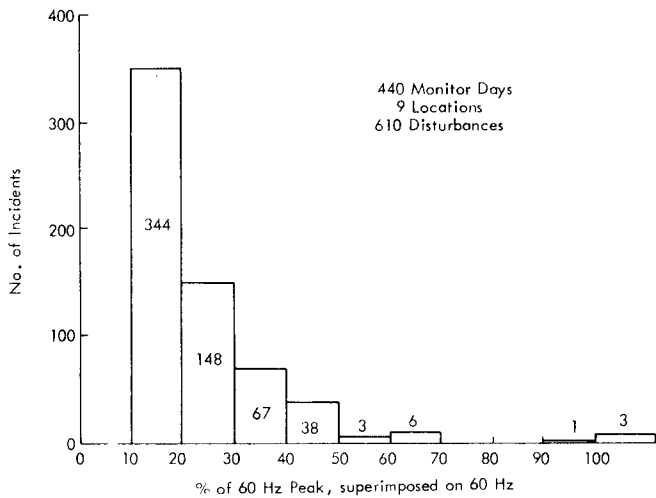


Figure 2. Plot of Switching Disturbances From Phase One Monitoring

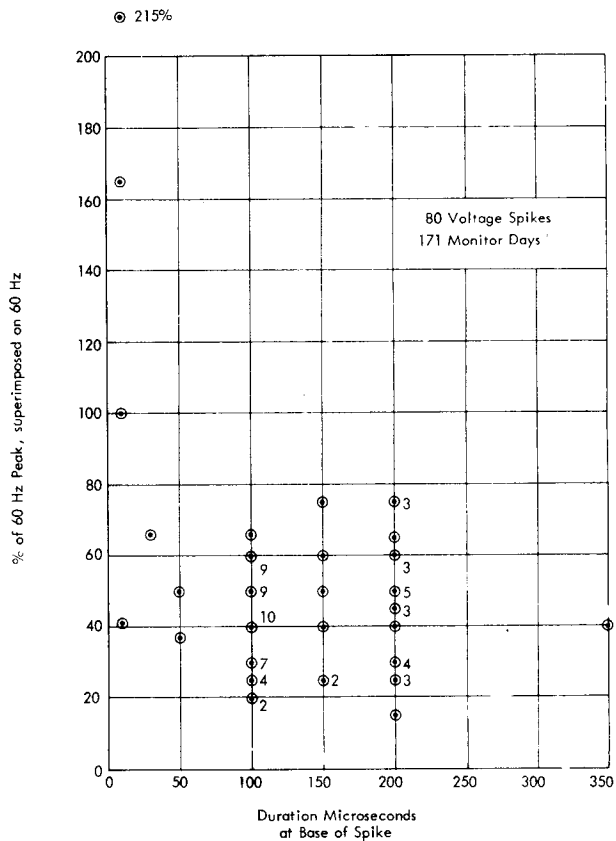


Figure 3. Plot of Spike Disturbance From Phase one

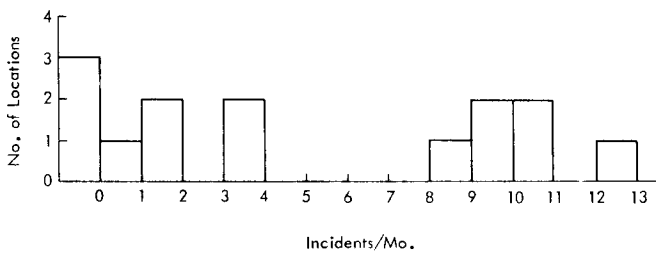


Figure 4. Incident Rate Plot For Under-voltage, Phase One

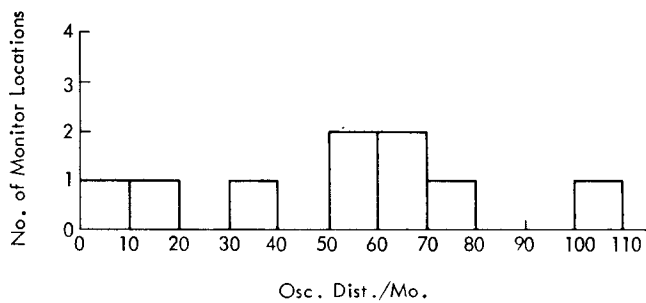


Figure 5. Incident Rate Plot For Switching, Phase One

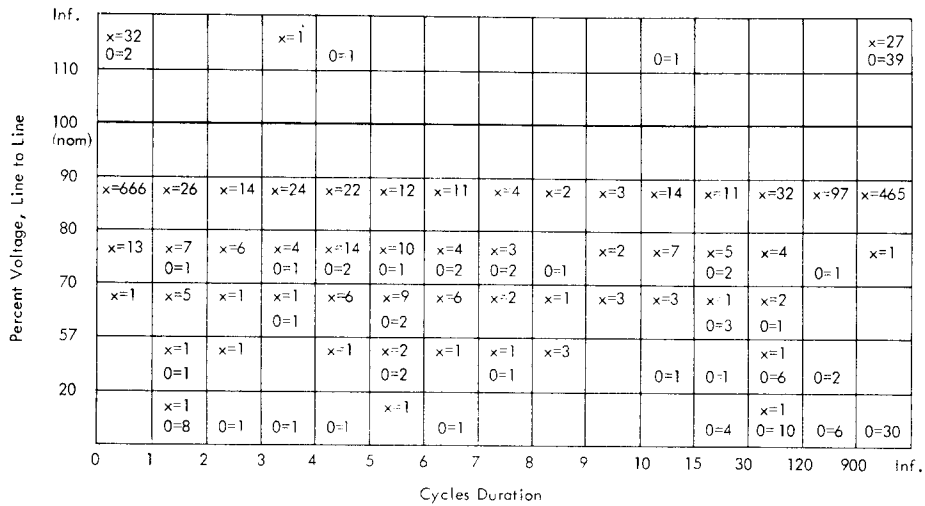


Figure 6. Under and Over Voltages, Digital Monitors

Key 0=30 > 110%  
0=30 < 80%  
x=others

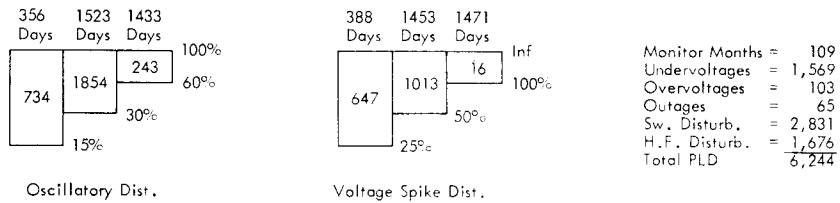


Figure 7. Switching and Spike Data From Digital Monitors

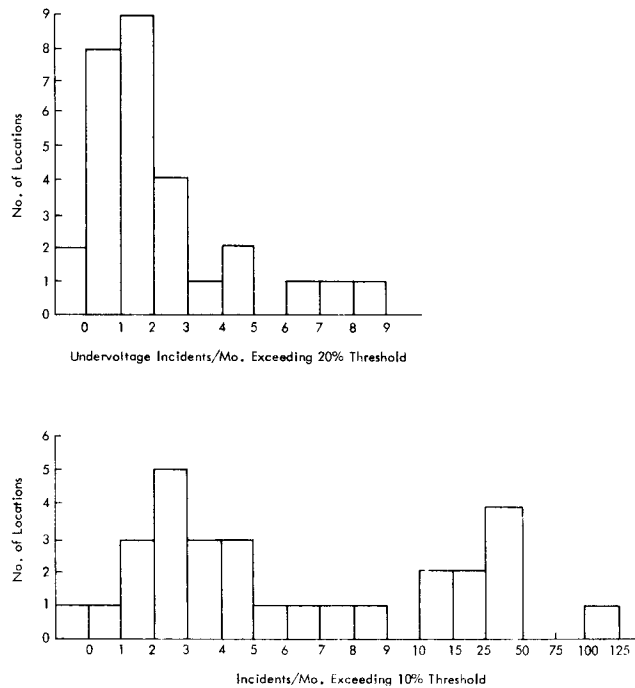


Figure 8. Undervoltage Incident Rate Plot, Digital Monitors



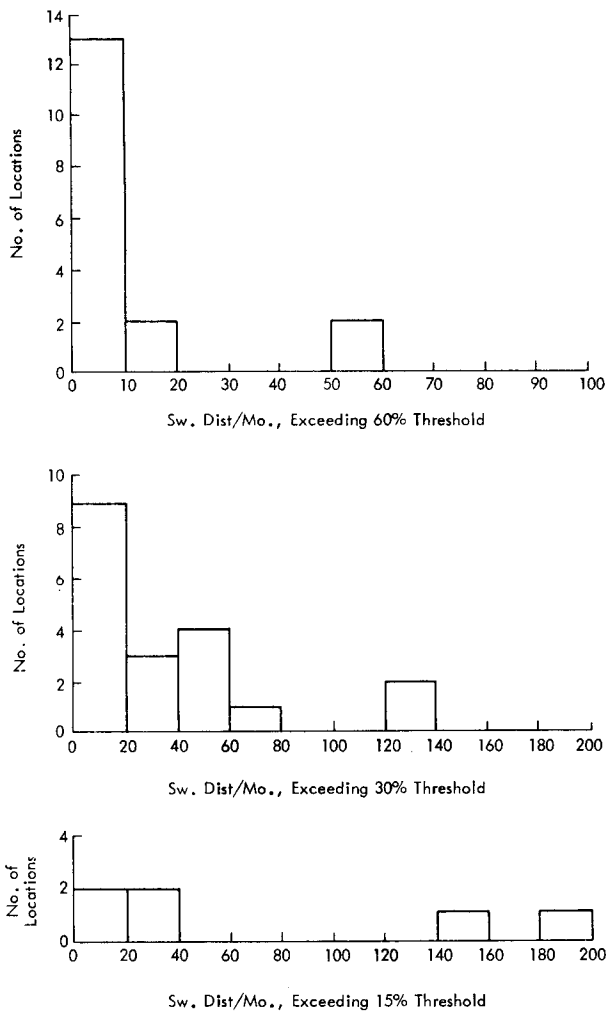


Figure 9. Switching Incident Rate Plot, Digital Monitors

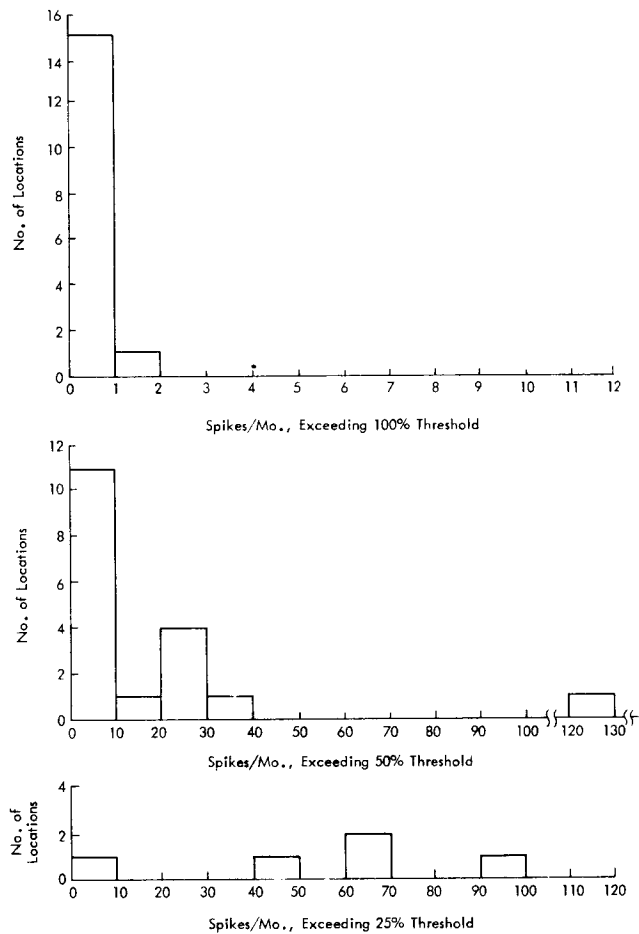


Figure 10. Voltage Spike Incident Rate Plot, Digital Monitors

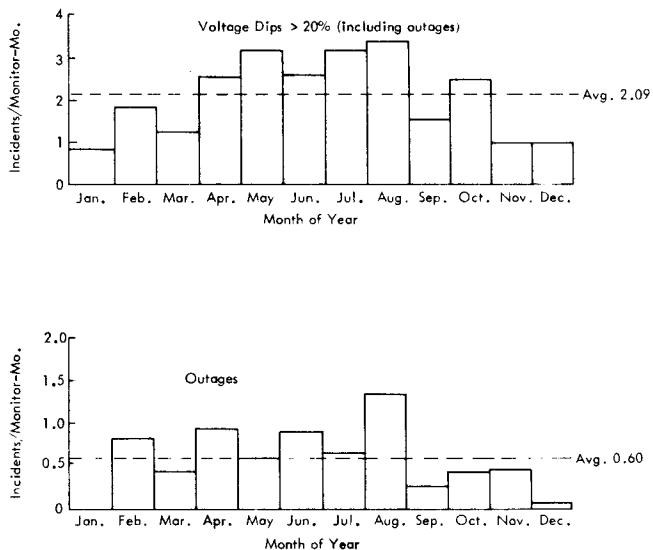


Figure 11. Monthly Distribution of PLD Incident Rates From Domestic Digital Monitor Data

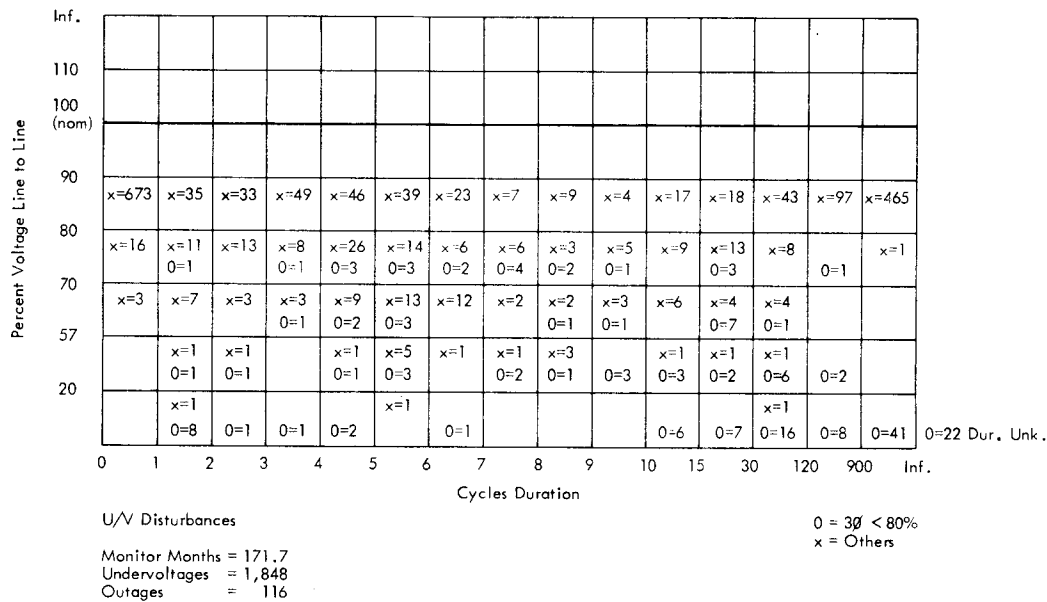


Figure 12. Cumulative Percent of Outages vs Duration in Minutes

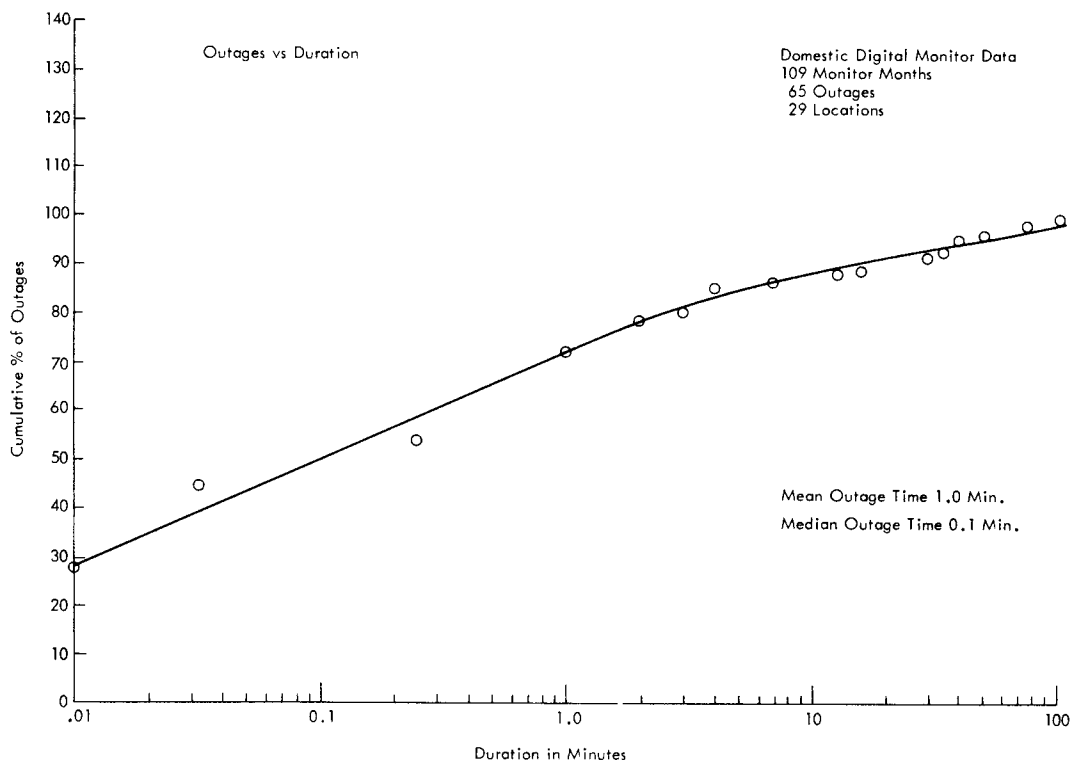


Figure 13. Total Undervoltage Data Plot

Discussion of  
Paper C74 199-6  
Monitoring of Computer Installation  
for Power Line Disturbances

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## DISCUSSION

The contribution by the authors of the data presented in their paper is significant in an area where much too little is available; however the data presented may be biased by instrumentation limitations for the recording of very short duration spikes, especially if their peaks exceeded the expectations implied in the instrument settings. This may be a partial explanation for the results showing lower peaks than the Reference 6 paper. Another explanation may be that the systems monitored in this study have lower impedance, and consequently would not allow the voltage caused by load switching rise to the levels recorded in the "softer" residential circuits. The nature of the distribution system (overhead versus underground) may also have an effect on the levels of spikes due to lightning remnants. To address this question, it would be useful if the authors could give a brief description of the type of power systems monitored. This would also provide the beginning of an appraisal of the energy levels involved, corresponding to the reported voltage measurements.

The paper describes two phases of monitoring for spikes, the first with storage oscilloscopes, the second with a digital instrument receiving its information from a band-pass filter. A brief discussion of possible pitfalls or limitations in the case of short duration spike follows, for each type of instrument.

A possible shortcoming of the storage oscilloscope, when used as described, is illustrated in the three oscillograms. Oscillogram #1 shows the recording of a random spike occurring in a 120 volts AC system, with the controls of a Tektronix 549 oscilloscope set approximately as described in the paper presentation: 200 volts/division, 0.2 millisecond/division, and a zero trace. Inspection of the recording shows the occurrence of a 300 volts, positive spike, or about 1.8 per unit.

However, if the oscilloscope had been set to record higher spikes, as in the case of oscillogram #2, where the only change has been to set the voltage sensitivity to 1 kV/division, the same spike occurrence is now recorded as shown, where the 2200 volts negative spike is not lost by excessive beam speed, as was the case in oscillogram #1. Oscillogram #3 shows a detailed recording of the same spike using a conventional oscilloscope (1 kV/div., 5  $\mu$ s/div.).

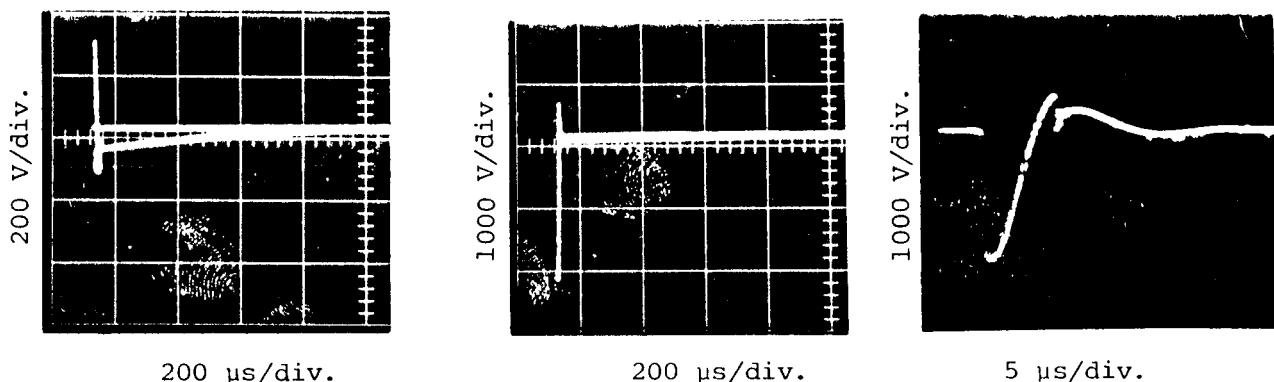


Figure 1. Spike Recording with Storage and Conventional Oscilloscopes

The question is then raised, whether the reported recording might have missed fast spikes at levels beyond the expectations of the observer. The peculiarities of the response to short spikes of a band pass filter, as discussed below, may unwittingly have confirmed this finding by attenuating the levels passed on to the threshold detection. Furthermore, the paper does not mention threshold settings higher than 100%, so that no evidence could be obtained for the higher levels.

The digital monitor (described in Reference 6 paper) may not respond as anticipated to the voltage spikes of 10 to 100 microseconds duration. The first item for examination is the transfer function for the transformer used at the input of the digital monitor. A normal 60 Hz instrumentation transformer could be expected to behave like a transformer up through 5 kilohertz. It would thus be useful for the authors to discuss the transformer behavior to inputs of the voltage spikes of interest.

The second item is the behavior of the 3-30 kHz bandpass filter to voltage spikes with the short duration of interest.

The peak output voltage of a bandpass filter is directly proportional to the bandwidth of the filter and the magnitude of the peak voltage spectral intensity of the voltage spike within the passband of the filter.

The filter response has been calculated assuming 1) that the bandpass filter has unity gain over the passband and zero gain at all other frequencies, 2) that the voltage spikes are square with a rise and fall time much shorter than their duration.

Fig. 2 is a plot of the peak voltage at the filter output as seen by the peak voltage detector as a percentage of the assumed square wave input voltage vs. the width of the square wave. The response may be even less for the typical power system voltage spikes.

We thus request the authors to further discuss the recording characteristics of both described spike monitoring systems as a function of pulse width.

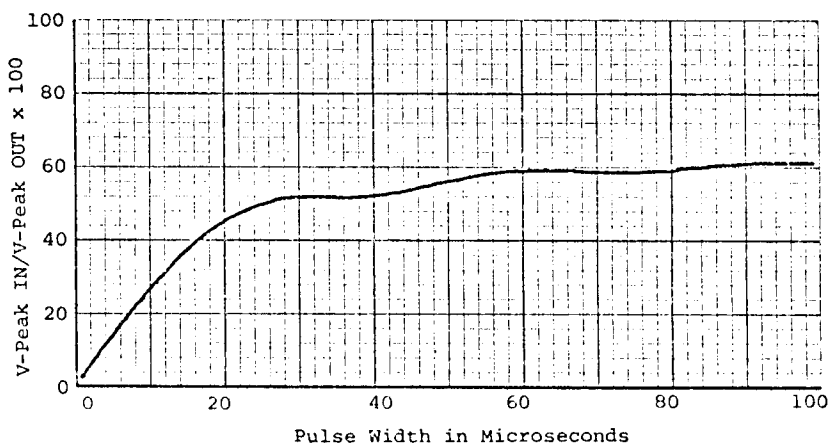


Figure 2. Filter Response